The influence of spatial attention on pain perception

-Bachelor thesis -

Ricarda Braukmann

s0163066

University of Twente

Tutors: Dr. Rob van der Lubbe, Msc. Jorian Blom

Cognitive Psychology and Ergonomics

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Abstract

This study investigated the effects of spatial attention on pain perception. 16 healthy participants (mean age 22) received either high or low intensity painful electrical stimulation on either their right or left upper forearms. A cue predicted the correct location in 80% of the cases and participants were instructed to classify the received stimulus as either high or low. Earlier research suggested that attention modulated early perceptual processes in painful stimuli. In this study, a decrease in reaction time in the attended trials was found which was in line with the assumption that attention would modulate the pain perception. On the contrary, using Signal Detection Theory, no change in sensitivity was found, indicating no effect of attention. It was concluded that there was evidence for an influence of attention on the perception of painful stimuli but that the results were dissonant which makes further research necessary.

Introduction

Of all the sensory modalities, the experience of pain is the most intense. Pain draws attention away from anything else. For example, imagine yourself cutting in your finger while preparing a meal for diner. As soon as you experience the sharp pain, it is impossible to concentrate on making diner since your attention is completely occupied by the pain. Pain is subjective as its experience depends on several personal characteristics. If you fear going to the dentist you might feel pain as soon as he touches one of your teeth to check for caries. A trained boxer who has been in many fights will describe pain differently compared to a housewife who has never been fighting in her whole life. Next to these personality factors, which influence the pain perception, there are several cognitive and emotional aspects, which can modulate perceived pain (e.g. Arntz, Dreessen & Merckelbach, 1991). Several earlier studies found that pain perception can also be influenced by attention (e.g. Moore, Keogh, & Eccleston, 2009) and the question of this study was in what way spatial attention influences the processing of painful stimuli. The focus lied on transient pain of short duration, which has to be distinguished from chronic pain deriving for example from a severe illness. Chronic pain patients suffer several cognitive and social dysfunctions, which have been examined in other studies (e.g. Hart, Martelli & Zasler, 2000). The discussion of chronic pain and its implications lies beyond the scope of this paper. After considering the main characteristics of pain and nociception, several related topics will be reviewed because of their relevance for the main question of this paper. These related topics include the differences between top-down and bottom-up attentional selection, the influence of other forms of attention on pain as well as the effects of pain on attention and the influence of spatial attention on tactile stimuli.

The international Association for the study of pain defines pain as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage” (Merskey & Bogduk, 1994). In pain research the sensory and emotional component described in this definition are often distinguished as nociception and pain. As described by van Damme, Legrain, Vogt and Crombez (2010, p.205) “nociception occurs when information about (potential) tissue damage is transferred to the brain by means of specialized nerves”. The detection of nociception occurs through special receptors attached to the Aδ and C fibers in the skin. (Loeser & Melzack, 1999). Pain on the other hand can be described as “the perception resulting from this nociceptive process” (Van Damme et al., 2010, p.205). Often Pain is measured by asking participants to rate a given stimulus using a Visual analogue scale (VAS) whereas the processing of nociceptive stimuli can be investigated using reaction times, Event-related potentials (ERPs) and several other methods.

According to the limited capacity model of human cognition, attention can be seen as a mechanism, which makes it possible for certain stimuli to enter awareness. By voluntarily shifting attention to a certain stimulus we are able to select this stimulus for further processing (Legrain, van Damme, Eccleston, Davis, Seminowicz & Crombez, 2009). On the other hand if we direct our attention away from a certain stimulus (for example a noxious stimulus), this stimulus will be excluded from further processing. Legrain et al. (2009) examined a model of attention to pain by extending this limited capacity model. They explored the effects of top-down and bottom-up attention. Top-down refers to a process were information is selected based on goal directed behavior and intentionality. In terms of attention, it is sometimes referred to as endogenous attention indicating that participants voluntarily shift their attention to certain event. Exogenous attention or bottom-up processing, on the other hand is a process whereby a salient stimulus (for example a flashing light) captures the attention of a subject. Exogenous attention seems to be independent of the intentions of the subject, which means that even if a subject knows that a cue (for example a flashing light) does not cover any relevant information its attention is still drawn to that cue due to its salient characteristics (Moore, Keogh, & Eccleston, 2009). The more salient a stimulus the more distracting its effects, making it difficult to attend to other stimuli or a given task. Most of the time a noxious stimulus is salient and would therefore, according to this model capture attention and distract from any other task. Several studies confirmed this assumption and the interrupting effects of pain on attention were outlined by Eccleston and Crombez (1999). They stated that the interruption of pain depends on the characteristics of the pain itself and on how threatening it is perceived as well as on the environmental and motivational aspects in the given situation.

In contrast to these bottom-up effects of pain on attention, there are top-down effects of attention on pain as well. Voluntary attending to a particular task instead of attending to a noxious stimulus can lead attention away from this stimulus decreasing the perceived pain (Hollins, 2010). Dowman (2003) for example examined the effects of an arithmetic distraction task on subjective pain ratings and pain-evoked activity in the anterior cingulate cortex (ACC). He found that subjective pain ratings were lower and ACC activity was larger during the distraction, indicating that a distracting task cannot only affect the subjective pain ratings but also pain-related brain activity. Quevedo and Coghill (2007) investigated the mechanisms involved in this alteration of pain perception by attention. They found that attention could alter the spatial integration of nociceptive stimuli. During a condition of divided attention, where each of the two simultaneous pain stimuli had to be rated, participants gave lower ratings compared to the condition, where they had to give an overall rating for both stimuli. According to Quevedo and Coghill, the latter condition lead to an integration of the two stimuli leading to a higher perceived pain, whereas divided attention abolished that spatial summation. An additional study on the effects of attention on pain perception was done by Zambini, Bird, Bentley, Watson, Barrett, Jones and Spence (2007). Their results suggested that attention lead to a faster processing of painful stimuli. They randomly presented two stimuli (one visual, the other painful) at different stimulus onset asynchronies (SOA) and instructed the participants to attend either to the visual targets, the pain stimuli, or both. The task of the participants was to verbally report whether the stimuli were occurring at the same time or if one was occurring later than the other. In the divided attention condition participants rated the stimuli as occurring simultaneously only if the painful stimulus occurred around 40 ms before the visual stimulus. Attending to the pain, the nociceptive stimuli had to occur later (compared to the divided attention condition) but still before the visual stimulus, in order to be rated simultaneously. When participants were attending to the visual stimulus on the other hand the nociceptive stimulus had to be presented even longer before the visual stimulus (compared to the divided attention condition) in order to be rated as simultaneously. This indicated that compared to a neutral condition where attention is divided, attending to a nociceptive stimulus speeds up its processing. These findings again are in line with the attentional model on pain suggested by Legrain et al. (2009). Attention can thus not only modulate the perceived intensity of pain but can also influence its temporal perception.

After discussing the effect of attention on pain perception in general, we will now focus on effects of spatial attention. An endogenous precuing task, which was used in this study, was one of the tasks recommended by Moore, Keogh and Eccleston (2009) who reviewed several studies on the effect of attention on pain for developing a test battery for further research on pain. In an endogenous precuing task subjects voluntary shift their attention to a particular location and receive an either valid (cued location) or invalid (uncued location) stimulus afterwards. In earlier studies, it was found that attending to the location where a given stimulus appears decreases the reaction times of participants. For example, Posner, Snyder and Davidson (1980) investigated spatial attention using several paradigms. In one of their experiments, participants had to detect a visual target and they had either seen a valid cue (80%), an invalid cue or a neutral cue prior to the stimulus. Posner et al. (1980) found that subjects reacted faster in the valid trials, where the cue predicted the location of the stimulus. Effects of spatial attention are not limited to one modality but can also be found with visual cues and tactile targets (Spence, Pavani, & Driver, 2000) as well as with visual cues and painful targets and vice versa. For example, Van Damme, Crombez and Lorenz (2007) reported an effect of pain on the processing speed of visual targets. They found that subjects reacted faster when a painful cue predicted the spatial location of the visual target. In our study we were interested in the reversed effect, namely in the effect of a spatial visual cue on the processing of a painful target. Legrain, Guérit, Bruyer and Plaghki (2002) investigated the influence of spatial attention on laser-evoked potentials (LEP). LEPs are brain waves, which occur after a noxious laser heat stimulus has been received. A LEP, elicited by Aδ fibers in the skin, mainly consists out of two parts, an early negativity (around 200 ms after stimulus onset) and a later positivity (around 400 ms after stimulus onset). In their experiment, participants randomly received laser stimuli on both hands with some stimuli occurring frequent and some occurring rarely (so-called oddballs). Participants were instructed to focus their attention on one hand and count the rare stimuli on that hand while ignoring all stimuli received at the other hand. The researches found an enhancement in two early components (N160 and

N230) of the LEPs for the attended trials, which was independent of the target's frequency. They interpreted this finding as an attentional modulation of the early processing of nociceptive stimuli. As the authors noted this early attentional modulation has been found in other modalities as well (e.g. Hillyard & Münte, 1984). Additionally to the early effects of attention the authors found that a later component of the LEP (P400) was influenced by the stimulus probability only. In a following study, Legrain, Guérit, Bruyer and Plaghki (2003) found that this modulation of the P400 by rare stimuli was only found when the stimuli were of high intensity. They therefore concluded that the modulation was due to an attentional shift based on the salient characteristics of the rare stimuli.

In our study we aimed to further assess the effects of spatial attention on pain perception by investigating effects on reaction times as well as on ability to discriminate between targets. Participants were instructed to shift their mental focus (attention) to one side, indicated by a visual cue. After the cue was delivered, participants received a painful stimuli on their forearm (left or right) which was of either low (expected VAS score of 3) or high (expected VAS score of 7) intensity. After receiving the stimuli either at the cued location (valid, 80%) or at the uncued location (invalid, 20%) participant had to classify the stimulus as either high or low by pressing a corresponding foot pedal. They were instructed to react as fast and as accurate as possible. As has been reported by several earlier studies it was expected that participants reacted faster to a given stimulus if they received a valid cue compared to an invalid cue (e.g. Spence, Pavani and Driver, 2000). As soon as the participants were instructed to react as fast as possible it was also expected that the error rate increased during the invalid trials. One possible explanation of an increase in reaction time on invalid trials is an enhanced processing of the attended painful stimuli. On the other hand, as Zambini et al. (2007) noted such a change in reaction time could also be caused by a change in the response selection or executional processes of the participants. Legrain et al. (2002) found an early modulation of pain-related brain potentials, supporting the first explanation. We therefore hypothesized that in our study the attended stimuli would be processed to a higher degree making it easier for participants to discriminate between a high and low intensity stimulus. To investigate this, we made use of the Signal Detection Theory (see appendix for a description of the SDT and the used measurements). SDT is a method, which can be used to compare sensitivity and response selection between attended and unattended trials. Sensitivity indicates in what way a participant is able to discriminate between two targets (in this case high and low intensity painful stimuli) whereas response selection describes the strategy a participant holds. Lloyd and Appel (1976) reviewed studies using the SDT for examining effects on different modification of pain. As a general conclusion the authors stated that SDT is a powerful tool in pain research and a good method to compare effects of different condition as well as examine whether theses effects reflect a change in sensitivity or are merely due to response bias.

In earlier research on cross-modal spatial attention (e.g. research on visual-tactile links by Kennett, Eimer, Spence & Driver (2001)) several researchers included a condition where participants had to cross their hands. Using such a condition makes it possible to investigate whether the spatial effects are modulated by the anatomical position of the two stimuli (for example right visual field and right arm) or if the effects can be explained by a common external location (for example right visual field and left arm lying on the right side). Crossing their hands could affect participant's ability to orient their attention to a particular spatial location. Spence, Pavani and Driver (2000) found reversed spatial effects with crossed hands indicating that the location of the stimuli is mainly important. In the crossed hand condition, a remapping of the modalities can take place, which means that for example the left arm of the participants (lying on the right side during a crossed hand trial) can be matched with stimuli occurring in the right visual field of the participant. In our experiment all participants had to cross their hands during the second and fourth block. It was expected that the crossed hands condition reveals comparable attentional effects as the normal condition. That would indicate that the spatial location not the anatomical position modulates the attentional effect.

In our experiment, electrical stimulation of the forearm was used for the painful stimulation. Compared to heat stimulation, electrical stimulation enables the researcher to control the timing of the stimulation (van der Heide, Buitenweg, Marani & Rutten, 2009). Some researchers using laser stimulation report that the location of stimulation has to be varied during the experiment in order to avoid tissue damage (Koyama, McHaffie, Laurientie & Coghill, 2005). Therefore electrical stimulation carries the advantage that the spatial location of stimulation can stay the same during the whole experiment. For the stimulation Pulse Train modulation was used which is a method where several pulses of the same amplitude are used to increase a higher perceived pain. According to van der Heide et al. (2009) this method is superior to single pulse stimulation where simply the amplitude of the stimulus is varied. The main advantage is that during pulse train modulation the same amount of fibers in the skin are activated with both high and low intensity stimulation which can not be guaranteed with the single pulse stimulation.

In summary, during a spatial cueing task, we expected participants to react faster and more accurately in the attended trials compared to the unattended trials. Furthermore, we expected that participants were better in discriminating between the high and low stimuli during the attended trials.

Methods

Participants

In this study 16 healthy adults (7 female) with a mean age of 22.31 years (ranging from 20 to 25 years) were tested in a three-hour session. All participants were students of either the University of Twente (14 participants) or the Saxion Hogeschool (2 participants). Half of them were students Psychology from the University of Twente. All participants were right handed and had normal or corrected to normal vision. None of the participants had a history of neurological, psychiatric disease or any sign of chronic pain disorder. Prior to the experiment all participants signed an informed consent and they were paid 18€ for their participation. The study was approved by the ethical commission of the University of Twente.

Inclusion and exclusion criteria

Participants had to be right handed and between 18 and 25 years old for participation. Several studies (e.g. Lane, Lefebvre, Rose & Keefe, 1995; Moore et al., 2009) pointed out that caffeine, alcohol and nicotine can have influence on both attention and perceived pain. Therefore all participants were instructed beforehand to avoid caffeine and nicotine on the day of the experiment. Furthermore one participant who had used alcohol and drugs the previous day and one participant who had a history of cognitive and neurological dysfunctions were excluded from participation.

Procedure

For other experimental purpose, EEG data was conducted using 61 Ag/AgCL ring electrodes on a standard 10/10 cap. In order to correct for eye movements and changes in heart rate, three bipolar electrodes were used. Electrodes were placed on and beneath the clavicula, above and under the left eye and next to the left and right eye of the participants. Preparation of the electrodes in order to maximize the quality of the recorded EEG data took between 60 and 90 minutes for most of the participants. After initial preparations were complete, participants completed a questionnaire to measure their hand preference (Annet, 1970). Furthermore a mood scale (Thayer, 1989) was assessed before and after the experiment to measure possible mood changes. After completing the initial questionnaires, the pain stimulation electrodes were attached to the left and right upper forearm and the experimental procedure was explained.

Prior to the four experimental blocks, several thresholds were assessed. The participants received stimuli of 5 pulses, growing in strength and responded whenever

1. The stimulus began to feel painful (pain detection threshold)
2. The stimulus was felt (sensation threshold)
3. The stimulus reached a maximum of pain the participant wanted to receive during the experiment (pain tolerance threshold)

This procedure was repeated three times for each arm. The mean pain tolerance amplitude of the three sessions represented the *high* stimulus during the experiment. For the *high* stimulus, participants received five pulses of certain amplitude, while two pulses of the same amplitude served as the *low* stimulus.

Task

After assessing the thresholds, every participant had to complete four experimental blocks containing 100 trials each. Prior to the first block all participants had a practice session of 16 trials, which included visual feedback to assure that the participants understood the task and reacted properly. Prior to each experimental block participants received four stimuli (two for each arm) serving as examples of high and low intensity stimuli.

Figure 1 shows the timeline of our experiment. Each trial started with the presentation of two arrows (one red, one blue) which served as a spatial cue. Prior to each block participants were instructed to fixate on a cross on the middle of the screen and to shift their attention to the location where one of the arrows was pointing at. One half of the participants was instructed to use the red arrow as a cue for the first two blocks and the blue arrow for the second two blocks while the other half of the participants was instructed vice versa. The direction of the relevant arrow was determined in a pseudorandom manner, assuring that one-half of the trials were cued left and the other half right. During the second and fourth block all the participants had to cross their hands. They were instructed to still shift their attention to the side indicated by the relevant cue while ignoring the fact that the other hand was lying at that side.

As can be seen in figure 1, the fixation cross was presented for 1200 ms, followed by the two arrows which were presented for 400 ms. Stimuli were delivered 600 ms after cue offset on either the cued location (80%) or the uncued location (20%). The intensity of each stimulus was determined in a pseudorandom manner, assuring that in one-half of the trials a low stimulus was used and in the other half a high stimulus. Participants were instructed to react as fast and as accurately as possible and to indicate whether the stimulus was high or low. Reaction was possible through the use of foot pedals. Half of the participants were instructed to use the right pedal for low and the left pedal for high stimuli, the other half were instructed vive versa. Each trial ended 4000 ms after stimulus onset even if no response was given.

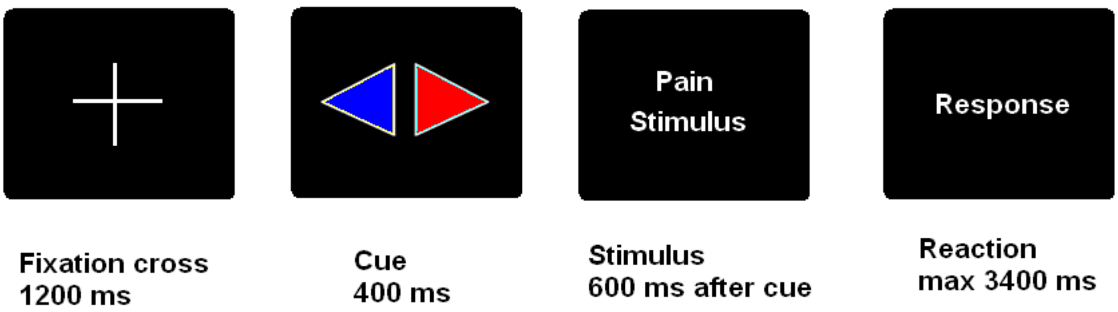

Figure 1 Timeline of the experiment

At the end of each block participants had to rate 4 stimuli (2 for each arm, one of high and one of low) which were delivered in a random order. The rating was done using a digital continuous VAS scale (see figure 2). The participants could use a slider to mark how painful they experienced the given stimulus. Between every block there was a short break to assure that the participant was doing fine.

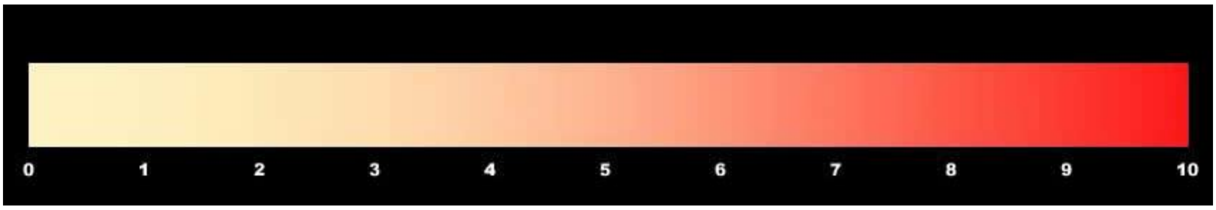

Figure 2. VAS scale with which participants rated the intensity of stimuli at the end of each block

Apparatus

Participants were seated in front of a 15-inch computer screen at a distance of about 70 cm. The room was darkened and silent during the execution of the task. Eprime (2.0.08.22) was used for presentation of all stimuli except for the pain stimuli. For the electrical stimulation a DS5 constant current stimulator (Digitimer, Welwyn Garden City, UK) was used with four stimulation electrodes (two for each arm) which were attached to the upper forearms of the participants.

Data Analysis

The acquired data was analyzed using SPSS (statistical package of the social sciences) 16.0. A significance level of α=0.05 was used for all the statistical tests.

Because of a software error occurring during pain stimulation several trials had to be removed and were not used for the final analysis. To make sure that the erroneous trials did not affect the results adjacent trials were also removed. Therefore, 138 trials (2.2%) had to be removed in total with a maximum of 24 trails (6.0%) for one participants and a mean of 9 trials (2.3%) per participant. Furthermore, trials where reaction time exceeded a maximum difference of 3 standard deviations from the mean (878.79 +/- 3 * 360.91 ms) were excluded. Therefore another 116 trials (1.8%) had to be removed with a maximum of 26 trials (6.8%) for one participant and a mean of 9 trials (2.3%) per participant. For each participant at least 374 trials remained for statistical analysis (mean 384).

In order to test our hypothesis and investigate main and interaction effects a 2*2*2*2 repeated measures ANOVA was used for the analysis of the reaction times. The within subject factors we used were *hands* (normal vs. crossed), *time* (first half of the experiment vs. second half of the experiment), *stimulus* (high vs. low) and *attention* (attended vs. unattended). Whenever a main effect was found a 95% confidence interval was calculated.

For the analysis of the changes in sensitivity and response bias we made use of Signal Detection Theory (SDT). During the analysis of the SDT data, it appeared that 5 participants had a *Hit rate* of 100% and/or a *False alarm rate* of 0%. These participants were removed from the analysis of the SDT data because the SDT model requires that the distributions of signal and noise have at least some overlapping space (for an extensive review of the SDT, see appendix). We calculated the values for the sensitivity (d') and response strategy (β) across the remaining 11 participants for the two sorts of trials (attended vs. unattended) using the formulas described by Macmillian and Creelman (2005). Furthermore we calculated the *Percentage of correct responses* (PC) across all participants for the attended as well as the unattended trials.

Additionally, to assess if there were differences between the thresholds measured at the beginning of the experiment we used a 3*2 repeated measures ANOVA with *threshold* (detection vs. sensation vs. tolerance) and *arm* (left vs. right) as within subject factors. Paired sample t-tests were used to check for differences in mood before and after the experiment. Finally, to assess whether habituation took place we analyzed the VAS scores obtained after each block using a 4*2*2 repeated measures ANOVA with *block* (first vs. second vs. third vs. fourth), *stimulus* (high vs. low) and *hand* (right vs. left) as within subject factors.

Results

Figure 3 shows the reaction times in the attended and unattended trials. There was a main effect of *attention* ($F(1,15)=22.5$, $p<0.01$). Participants reacted significantly faster on the valid trials compared to the invalid trials. When attending to the stimuli participant's average reaction time was 839 ms (SE=39.0 ms) compared to 908 ms (SE=44.5 ms) in the unattended trials. Attention did not influence the errors participants made, as soon as there was no difference in PC ($t(15)=-0.2$, $p=0.08$) between the attended and unattended trials (see Table 1). Additionally, the stimulus intensity had no influence on the reaction speed of the participants ($F(1,15)=3.3$, $p= 0.09$) and there was no interaction between *stimulus* and *attention* ($F(1,15)=0.01$, $p=0.91$).

Next to the main effect of *attention* there was a main effect of *hands* ($F(1,15)=10.4$, $p<0.01$) and additionally a main effect of *time* was found ($F(1,15)=33.1$, $p<0.01$) On average participants were 34 ms faster (SE=10.8 ms) when their hands had to be crossed compared to the condition were their hands were lying next to each other. Furthermore, participants on average reacted 64 ms (SE=11.1 ms) faster during the second half of the experiment compared to the first half.

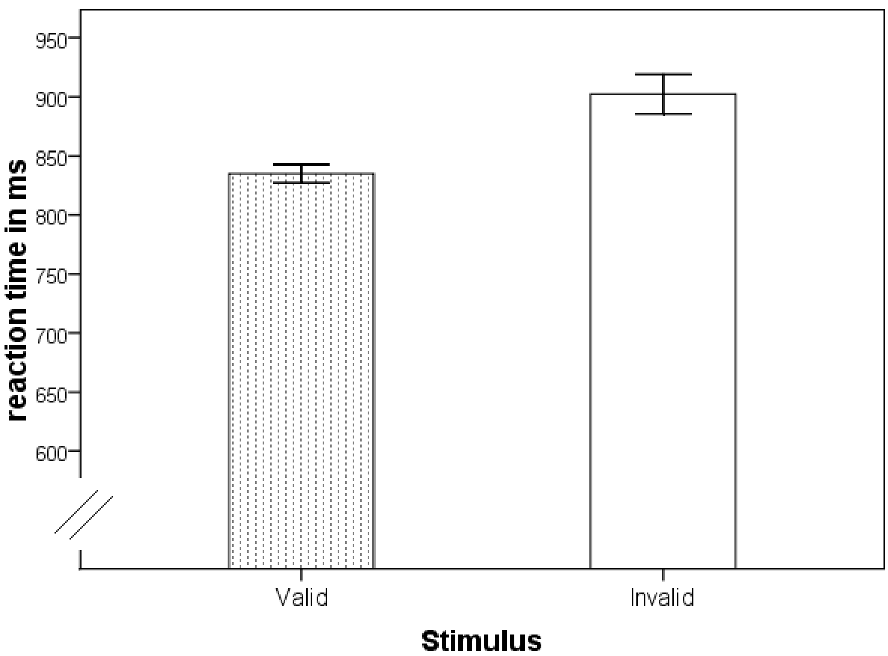

Figure 3. Difference in reaction time between the attended and unattended trials

There was an interaction effect between *time* and *hands* ($F(1,15)=4.7$, $p<0.05$). As can be seen in figure 4, the difference between the reaction times in the hand conditions was bigger during the first half of the experiment, compared to the second half.

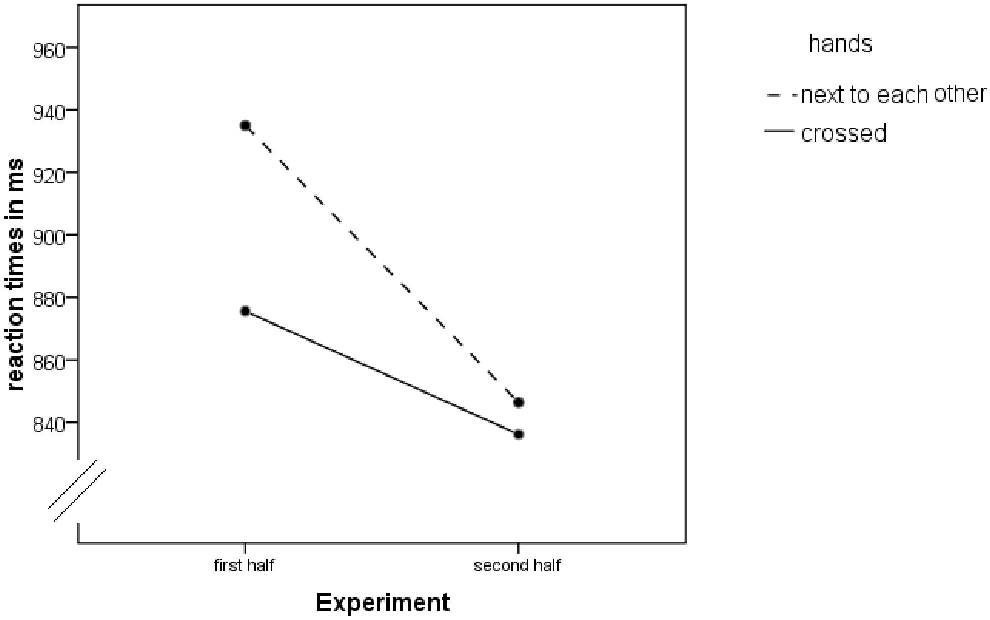

Figure 4. Interaction effect between *time* (first half vs. second half of the experiment) and *hands* (crossed vs. uncrossed)

Table 1 shows the *Hit* and *False Alarm rates* calculated across participants (n=11) for the attended and the unattended trials. Furthermore PC, as well as the d' and β value for the attended and unattended trials can be found in Table 1. As mentioned before there were no significant differences between the errors participants made in the attended and unattended trials ($t(15)=-0.2$, $p=0.84$). Furthermore no difference in *Hit rates* ($t(10)=-0.40$, $p=0.70$) or *False alarm rates* were found ($t(10)=-0.02$, $p=0.99$). Additionally there was no difference between the d' values ($t(10)=0.40$, $p=0.70$) nor between the β values ($t(10)=-0.81$ $p=0.44$) when comparing the attended and the unattended trials.

Table 1. Hit-rate, False alarm-rate and percentage of correct responses (PC), as well as d' and β for the attended and the unattended trials, calculated across participants. The high stimulus was seen as the signal, the low stimulus is seen as the noise. Therefore *Hits* were the trials where a participant received a high stimulus and rated it as high, *False alarms* were the trials were a participants received a low stimulus and rated it as high. For the analysis of the Hit rate and the False Alarm rate as well as for d' and β 5 participants were excluded.

	Attended	Unattended
PC (n=16)	0.90	0.90
Hit rate (n=11)	0.83	0.84
False Alarm rate (n=11)	0.08	0.08
d' (n=11)	2.57	2.62
β (n=11)	2.76	2.09

Concerning the thresholds which were calculated at the beginning of the experiment a difference was found between the three thresholds ($F(14,2)=5.6$, $p=0.02$). The pain tolerance threshold was higher than the pain detection threshold for all participants. There was no difference between the ratings for the left and right arm of the participants ($F(14,2)=0.33$, $p=0.575$). This indicated that participant rated the stimuli similar for their left and right arm and there was no difference in sensitivity to pain between the arms.

After each block participants had to rate four stimuli (two for each hand) two high and two low. A main effect of *stimulus* ($F(1,15)= 57.90$, $p<0.01$) revealed that the high and low stimuli were clearly rated differently. On average the VAS score for the low stimulus was 2.5 (SE=0.3) and the VAS score for the high stimulus was 5.4 (SE=0.3). There was no difference between the ratings of the stimuli given to the left or to the right arm ($F(1,15)=0.24$, $p=0.63$). Additionally there was no effect of *block* indicating that participants rated the stimuli comparable during the entire experiment ($F(3,45)=2.52$, $p=0.70$). This suggested that there was no habituation of the participants.

Several paired sample t-tests revealed that there were no differences in the mood of the participants comparing the ratings before and after the experiment. All p-values were far from significant ($0.29 < p < 0.98$) except for the score of “onverschillig” (indifferent) ($p=0.06$). A 95% confidence interval showed that participants scored higher on the mood indifference after the experiment, although it has to be noted that this effect did not reach the significance level.

Discussion

This study investigated the effects of spatial attention on pain perception. Participants received either high or low intensity electrical stimulation at an either cued or uncued location and had to classify the stimulus as either high or low.

As expected, participants were faster rating the stimuli at the attended location compared to the unattended location. This was in line with earlier experiments on spatial attention (e.g. Posner et al., 1980). This result supported the idea of attention as selection mechanisms, such as it was described in the limited capacity model of attention (see Legrain et al., 2009). There was no difference in the errors participants made. They were instructed to react as fast and as accurate as possible and therefore it seemed likely to assume that a change in reaction time during the attended trials would be paired with an increase in the errors made. This was not confirmed.

As Zambini et al. (2007) noted a change in reaction speed could either occur due to a change in perception of the attended stimuli or it could be due to changes in the response selection or execution processes of the participants. Legrain et al. (2002) found that attention modulated the amplitude of Laser evoked potentials (LEP) at an early stage suggesting that the perception was altered rather than the response. We therefore expected that attention would lead to a more accurate perception of the stimuli itself, leading to a higher sensitivity, which we measured using Signal Detection Theory (SDT). The sensitivity measure d' was quite high in both the attended ($d'=2.57$) and unattended trials ($d'=2.76$) indicating that participants were clearly able to discriminate between the two stimuli. The response strategy indicated by β was conservative, meaning that participants would rather classify a stimulus as low. There was no difference in β between the attended and unattended trials, which implied that participants did not change their response strategy. More importantly, the expected difference between the sensitivity in the attended and unattended trials has not been found either.

These findings seemed in contradiction with the expected change in perception, which we hypothesized could account for the found enhancement of reaction speed during attended trials. Still, it has to be noted here that there are several explanations for the absence of differences in the errors as well as in d' and β. It seemed that the task was rather easy for the participants, as percentage correct was quite high (90%). In line with that, Abdi (2007) noted, that if the hit rate is quite high and the False alarm rate quite low, this mostly implies that participants find it rather easy to discriminate between the signal and the noise. If the task is too easy the use of SDT is questionable because this means that the signal and noise distribution show few overlap (represented by a high d' value). As can be seen in Table 1 participants had a Hit rate of 0.83 in the attended and 0.84 in the unattended trials, as well as a False alarm rate of 0.09 in both attended and unattended trials, which clearly indicated that participants found it easy to discriminate between the targets. Additionally the distance of the two distributions seemed quite big as indicated by a d' of 2.57 in the attended and a d' of 2.62 in the unattended trials. Furthermore there were 5 participants who had a Hit rate of 100% and /or a False alarm rate of 0% and were therefore removed from the analysis. According to the model of the SDT there has to be at least some overlap between the distributions of signal and noise, which would make such results per definition impossible. Therefore it stays questionable in what way SDT can be useful for the analysis of our data. In addition, it has to be noted that there was a huge difference between the numbers of trials. Only 20% of the trials were invalid leading to a mean of 76 unattended trials per participants, whereas there were a mean of 308 trials per participant in the attended condition. A slightly increase of the probability of unattended trials could lead to a higher number of trials without completely abolishing the effect of attention. Having a more comparable number of trials for attended and unattended stimuli would give better and more valid insights in possible changes in response strategy as well as in sensitivity. Additionally it has to be noted here that the participants who were removed from analysis because of 100% Hit rate (0% False alarm rate) all showed this extremely high score during the invalid trials. We suggest for further research to change the difference in intensity between the two stimuli in order investigate attentional effects on more ambiguous painful stimuli. It might also be important to stress the speed instruction in order to make the task more difficult for the participants.

In our study top-down effects of attentional selection were found as attention influenced the speed of reaction. No bottom-up effects of the stimuli were evident, as there was no influence of stimulus intensity on reaction times. Earlier research (e.g. Eccleston & Crombez,1999.) suggested that more salient stimuli capture more attention. In contrast to these findings the varying intensity of our pain stimuli did not cause different reaction times indicating no influence of pain on attention. The high stimuli had a mean rating of 5.4 on a visual analogue scale during the ratings after each block and it might be that this was not salient enough to capture attention. On the other hand it could be possible that top-down and bottom- up attention influence each other. In our experiment we found no interaction between the stimulus intensity and the spatial attention effects, which could indicate that there is no interaction between the two processes. Additionally Hahn, Ross and Stein (2006) found that different brain regions were engaged in the bottom-up and top-down processing in visual spatial attention. It would be interesting to investigate bottom-up and top-down effects and their interaction in pain processing and therefore it could be beneficial to increase the saliency of the pain stimuli.

A main effect of hands was found during the experiment, which was not expected. Additionally there was an interaction between time and hands. During the experiment participants had to cross their hands during the second and fourth block. It was found that participants reacted faster during the crossed hands blocks compared to the blocks where their hands lied next to each other. This effect seemed illogical at first but a closer look revealed that it might be due to our experimental composition. A main effect of time revealed that participants were faster in the second half compared to the first half, which indicated that participants adapted to the task and therefore were able to speed up their response. As soon as participants had to cross their hand in the second and fourth block, we assumed that the effect of hands might be because the condition was placed later in time in the experiment. The interaction effect of time and hands (see figure 4) supports this interpretation as it can be seen that the difference between the crossed hand condition and the normal condition is bigger during the first half of the experiment where participants need to get used to the task. As long as we did not counterbalance the place in time of the crossed hands condition we cannot say for sure where these effects come from. For further research we suggest to vary the place in time of such a condition in order to correct for interaction effects with time. It has to be noted here anyway that there was no interaction with attention and the hand condition, which is in line with the expectation that the attentional effect would not be disturbed by the fact that participants cross their hands.

If attentional effects are found in a study the question remains if these effects represent an enhancement of response time in the valid conditions (benefits) or a decrease of response time in the invalid condition (costs). To investigate this question, earlier studies on spatial attention included a neutral cue condition (e.g. Posner et al., 1980). Using such an experimental condition makes it possible to investigate the costs and benefits rather than investigating overall attentional effects only. The difference between the invalid and the neutral trials can be seen as costs, whereas the difference between the valid and the neutral trials can be seen as benefits. Forster and Eimer (2005) investigated the costs and benefits for tactile spatial attention. Participants had to detect a target tactile stimulus and either received a valid, invalid or neutral cue, indicating the location of the target stimulus. They found that participants reacted fastest on valid trials, average on neutral trials and slowest on invalid trials. Reaction time benefits (RT neutral- RT valid) and costs (RT invalid – RT neutral) were calculated and it was shown that the costs exceeded the benefits. The authors concluded that both costs and benefits contributed to the effects of spatial attention which indicated that both facilitation (from processing attended stimuli) and inhibition (form switching to uncued locations) contributed to the attentional effects. For following studies on the influence of spatial attention on pain it is beneficial to investigate the costs and benefits by using a neutral condition.

In summary, the found effect of attention on reaction times was in line with earlier research suggesting that attention did change the perception of painful stimuli. On the contrary, the analysis using SDT did indicate no difference between the attended and unattended trials, neither on perceptual nor on response selection level. Therefore no strong conclusion can be drawn. We suggest that in further research ambiguous painful stimuli are used. Additionally, the integration of more salient stimuli could be advantageous as interactions between top-down and bottom-up effects on pain can be further explored. Finally yet importantly, we suggest to add a neutral cue condition to investigate whether changes in reaction times are due to costs or benefits.

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Appendix

1. The Signal Detection Theory

Signal Detection Theory (SDT) can be used in any paradigm where participants need to make a decision and classify a given stimulus. Mostly experiments using the SDT for analysis use paradigms where participants have to detect a certain target (the signal) out of other distracters (noise) (Abdi, 2007). In our experiment, participants have to distinguish between high and low painful stimuli and these stimuli can be seen as signal and noise respectively. SDT assumes that signal and noise both have a certain distribution (see figure 5). The overlap of the two distributions therefore represents the difficulty in discriminating the signal and the noise. If the two distributions fit perfectly into one, there would be no difference between the signal and the noise. If on the other hand, there is no overlap between the two distributions, signal and noise are completely discriminable. As Abdi (2007, p.1) describes, the SDT has the goal “to estimate two main parameters. The first parameter, called d', indicates the strength of the signal (relative to the noise). The second parameter called C (a variant of it is called β) reflects the response strategy of the participant.”. As can be seen in figure 5, d' is reflected by the distance of the two distributions, whereas the criterion C is reflected as a horizontal line. The criterion C describes the strategy of the participant, which means that it is an

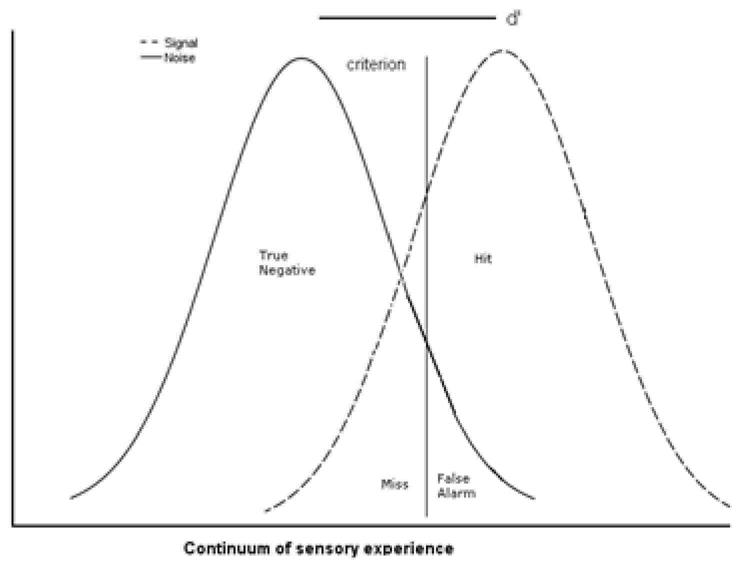

Figure 5 *Hypothetical noise and signal distributions.* The criterion represents the decision of the subject. The space left to the criterion represents a “No” (signal does not appear) wheras the space to the right represents as “Yes” (signal does appear). d’ represents the space between the two distributions as a measure of descriminability.

indicator of when a participant is likely to answer “YES” (a certain stimulus occurred). Mathematically C is the distance from the actual threshold to the criterion of the ideal observer. A related concept of C is β, also called the likelihood ratio. β describes “the ratio of the height of the signal distribution to the noise distribution for the value of the threshold” (see Abdi, 2007, p.6). Mostly d' and β are the reported statistics in research with SDT, therefore we also used theses two parameters in our experiment. Some participants are more likely to answer that a given signal occurred, even if it did not, and C and/or β can be used to measure this strategy and detecting response bias (see Macmillian and Creeman (2005) for exceeding information on response bias). A negative C value (or $0<\beta<1$) indicates that a participant is rather liberal (saying “YES” more often) whereas a positive C value (or $\beta>1$) indicates a rather conservative response style (saying “NO” more often) (Abdi, 2007). In general, in a task where a participant has to make a decision, there are four different response possibilities (see Table 2). On the one hand, a participant can answer that a certain signal occurred and it did (Hit) or it did not (Miss). On the other hand, a participant can answer that a certain signal did not occur and it did not (True Negative) or it did (False Alarm). Table 2 shows these possibilities for our experiment. We calculated d', β and PC using the following formulas (see Macmillian and Creelman, 2005) In these formulas H = p(“high”/high stimuli) represents the Hit rate and F = p(“high”/low stimuli) represents false alarm rate.

Table 2. Overview of the possible reactions in our experiment

	Pain stimulus	
Response Participant	High (Signal)	Low (Noise)
High	Hit	False Alarm
Low	Miss	True Negative

$$d' = z(H) - z(F) \quad (1)$$

$$PC = ½ [H + (1- F)] \quad (2)$$

$$C = ½ [z(H) + z(F)] \quad (3)$$

$$\ln(\beta) = C*d' \quad (4)$$

$$\beta= \exp\{\ln(\beta)\} \quad (5)$$